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5.8.5 Photovoltaics

Photovoltaic, or PV, cells are semiconductor devices that convert sunlight into electricity. They have no moving parts. Energy storage, if needed, is provided with batteries. PV modules are successfully providing electricity at hundreds of thousands of installations throughout the world. Especially exciting are building-integrated photovoltaic (BIPV) technologies that integrate PV directly into building materials, such as semitransparent insulated glass windows, skylights, spandrel panels, flexible shingles, and raised-seam metal roofing.

Opportunities

Photovoltaic systems are cost-effective in small applications removed from utility power. It costs less to serve a small load with PV than to install a power line, even on a first-cost basis. PV prices have historically declined about 5% per year, and PV systems are typically less expensive than operating a stand-alone generator in a remote location. Consider replacing small (less than 10 hp) generators with PV, especially in environmentally sensitive areas where maintenance and fuel spills are a concern. Increasingly, PV is being considered as a source of electrical energy for buildings—even those with ready access to utility power—with the PV system integrated into the building envelope.

Technical Information

At the heart of all PV systems is the photovoltaic cell. *Crystalline PV cells* are made from thin circular or rectangular silicon wafers sliced from single-crystal or polycrystalline silicon stock. Wafers are doped either with boron or phosphorus to provide them with special charge properties and are sandwiched together to create cells. Most crystalline PV cells are on the order of 8 to 17 mils thick and typically 12–14% efficient.

With thin-film PV cells, the semiconductor material is deposited directly onto a glass, plastic, or metal substrate in a very thin layer (usually less than 5 microns thick), thus dramatically reducing the amount of material used. Thin-film cells are produced today with one to three layers of amorphous (noncrystalline) silicon, very thin layers of crystalline silicon, or more exotic materials such as cadmium telluride or copper indium diselenide. Most thin-film PV cells are 5–10% efficient in converting sunlight to electricity.

Modules are produced by wiring PV cells together and sealing them between layers of protective materials—usually glass. For BIPV applications, crystalline cells can be custom-colored (standard colors are dark gray to deep blue) and spaced to allow light transmission between cells, and modules can measure up to about 30 sq ft (2.8 m^2) in area. Thin-film modules typically are a uniform gray color and can be semitransparent.

Modules, in turn, are assembled into *PV systems*, which can be either stand-alone or utility-interactive, as described below.

STAND-ALONE PV SYSTEMS

Stand-alone PV systems can be set up to function in several ways:

- **A direct-coupled system** is the simplest version and consists of photovoltaic cells driving a DC load with no battery storage. Loads such as water pumps, ventilation fans, and special DC refrigerators are good applications.
- **Battery storage systems to drive DC loads** store the PV-produced energy until it is needed—for example, to power navigation aids at night. The simplest version drives DC loads only and requires a battery with charge control to prevent overcharging.
- **Battery storage systems to drive AC loads** have a charge controller and an inverter (which changes DC to AC) to power connected AC loads. Hybrid systems may have one or more additional energy sources, such as a wind turbine or diesel generator.

Typical stand-alone applications include remote residential lighting and home power, emergency communications, irrigation systems for agriculture, microwave repeaters, cathodic protection for bridges and pipelines, navigation aids, security systems, meteorological stations, remote area lighting, and signboard lighting. There are hundreds of thousands of stand-alone PV systems worldwide.

UTILITY-INTERACTIVE PV SYSTEMS

Utility-interactive or grid-connected systems require an interactive inverter to operate with the grid. The PV power is first delivered to the load, and then extra electricity is sent to the grid. The inverter matches the output power to the phase and frequency of the grid. Some considerations are as follows:

- **Net metering**, legislated in a majority of states for residential-scale systems, allows the electric meter to literally spin backwards, giving full retail credit for electrical energy exported to the grid.
- **The Public Utilities Regulatory Policy Act** (PURPA) requires utilities to interconnect to any qualified facility. However, the facility must pay for the interconnection.
- **Technical and operating issues** that must be coordinated with the utility are metering, safety, equipment protection, service reliability, and power

quality. IEEE standards address interconnection with the utilities; UL standards apply to inverter and PV module performance and safety; the National Electrical Code governs wiring issues.

- **For situations in which the reliability of grid power is in doubt**, the PV system can be designed to automatically replace it during outages.
- **When planning a utility-interactive system**, be sure to check into metering options, buy and sell rates for power, outdoor disconnect requirements, insurance requirements, and other interconnection costs.

☑ Building-Integrated Photovoltaics systems combine electricity generation with other building envelope functions. A skylight, for example, can both provide daylighting and generate electricity. Spandrel panels in commercial buildings can be power-producing with little, if any, change in appearance. Raised-seam metal roofing and even shingles can serve a dual purpose: shedding rain and generating electricity. BIPV systems often have significant economic advantages over electricity-only PV systems because the BIPV modules are used in place of a building element.

PV SYSTEM DESIGN AND INSTALLATION

PV system design and installation can be complex. This is particularly true for utility-interactive systems and hybrid systems with supplemental power generation. System designers should be familiar with PV and balance-of-system equipment, as well as all applicable codes and regulatory issues. With BIPV systems, architectural expertise is needed to ensure proper integration with the building and satisfaction of building envelope requirements. Hiring experienced, fully qualified PV system designers is key to satisfactory performance, easy maintenance, and long system life.

$ In 1970, PV cells cost more than $1,000 per peak watt of power and were used mostly for exotic applications, such as spacecraft power systems. Prices today are under $4 per peak watt, wholesale, for standard modules. Complete stand-alone systems typically range between $6 and $12 per peak watt; BIPV systems range from $7 to $15 per peak watt but often earn a credit by replacing conventional building materials.

Source: Craig Miller Productions and DOE

The swimming and diving facility built for the 1996 Summer Olympics uses photovoltaics (front) to produce electricity and a solar-thermal system (back) to heat pool water. Both systems reduce demand on the local utility and result in significant annual energy and cost savings.

STORAGE SYSTEMS

Storage systems for PV arrays make it possible to use captured energy at night or whenever the PV system can't meet the load. A typical storage system is a set of batteries sized to accommodate the PV input as well as the load demand.

When selecting a battery system, the designer needs to consider cyclic and calendar life, daily depth of discharge, temperature and environmental conditions, offgassing characteristics, size and weight, cost, warranty, availability, reputation of the manufacturer, maintenance requirements, and terminal configuration.

Batteries often contain hazardous materials; the proper use and care of batteries should be a priority throughout their life cycle, including disposal.

References

Photovoltaic Fundamentals (DOE/CH10093-117), National Renewable Energy Laboratory, U.S. Department of Energy, revised February 1996.

Photovoltaic System Design Manual (FSC-GP-31-86), Florida Solar Energy Center, Cocoa, FL, revised April 1996.

Contacts

Contact the FEMP Help Desk, (800) DOE-EREC (363-3732), or see the FEMP Web site, www.eren.doe/femp/.

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